Chapter seven

D-C Motors

7.1 introductions

The construction, winding connection and types of motors are the same as that of d-c generators; the only difference is the energy conversion. In gen. mechanical power converted to electrical power, while, in motors elect. Power converted to mechanical power. This can be cleared in a power flow diagram (*PFD)* shown below, fig.(7.1).

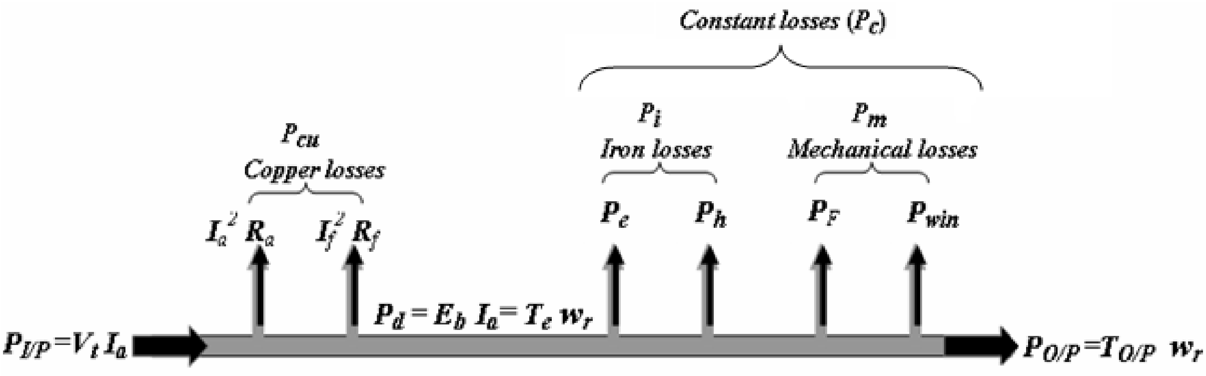

Fig.(7-1) Power Flow Diagram

The input Electrical power to the motor = $V_t\ I_a$ as indicated in the equivalent circuit shown in fig.(7.2) for a shunt-excited d-c motor.

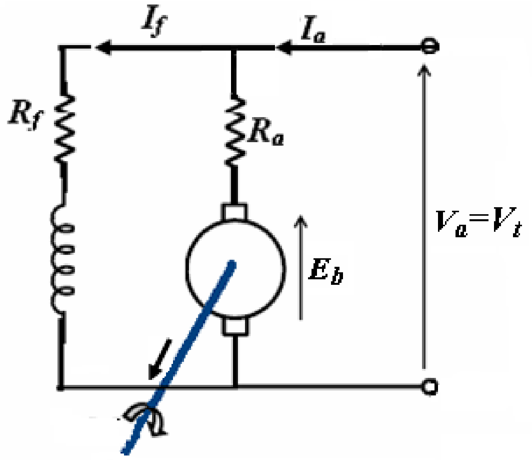

Fig.(7-2)

The copper losses in armature winding is $I_a^2\, R_a$ and that for field winding is $I_f^2\, R_f$, the rest power is shown as the developed power P_d, this is equal to $I_a\, E_b$, where E_b is the generated back *emf* in the motor and I_a is the armature current $P_d = T_e\, W_r$ which the mechanical power initiated in the motor, where, T_e is the electromagnetic torque & W_r is the rotational or angular speed of rotor in ***rad/sec***. This power will supply other losses in the machine due to its rotation these are

a) Iron losses P_i

These losses occurs in the iron of motor only, and these are two types

i) Eddy current losses .P_e

ii) Hysteresis losses P_h

b) Mechanical losses P_m

These are due to two different reasons

i) Friction losses P_F ; with bearings

ii) Winding losses P_w ; Friction with air inside the machine cavity.

Pi & Pm are both function of speed (n), so, when the speed is constant, these losses are considered constants and denoted by (Pc)

Hence $P_{o/p} = P_d - P_c = T_{o/p}\, W_r$,& $T_{o/p} < T_e$

7.2 Separately -Excited d-c motors

Applying KV L to the armature circuit results in

$$V_t = E_b + I_a R_a \qquad \text{……….(7.1)}$$

As $E_b = ke\, \Phi\, n$

$\therefore\ V_t = ke\,\Phi\,n + I_a\,R_a$

or

$$n = \frac{V_t - I_a R_a}{K_e\,\Phi}$$

$$n = \frac{V_t}{K_e\,\Phi} - \frac{R_a}{K_e\,\Phi} I_a \qquad \text{............. (7.2)}$$

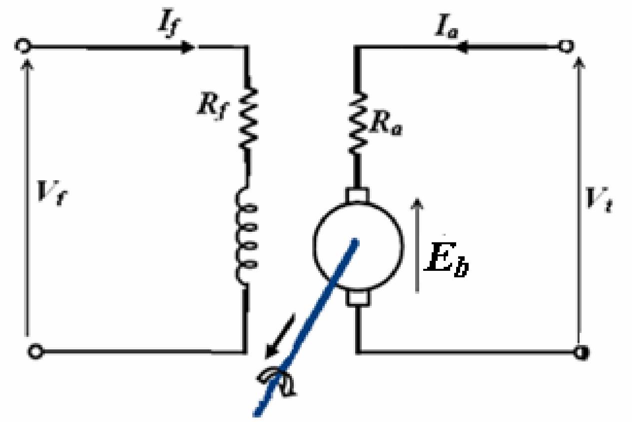

Fig.(7-3)

Eq'n (7.2) represents the relation between the speed of the motor and the armature current ***(n versus I_a)***. This relation is shown in fig. (7.4)

From (*PDF*)

$E_b I_a = T_e W_r$

$\therefore\ Ke\,\Phi\,n\,Ia = Te\,2\pi n$ .... (7.3)

$$\therefore\ I_a = \frac{2\pi}{K_e\,\Phi} T_e$$

or $$T_e = \frac{K_e}{2\pi}\Phi\,I_a \qquad \text{......... (7.4)}$$

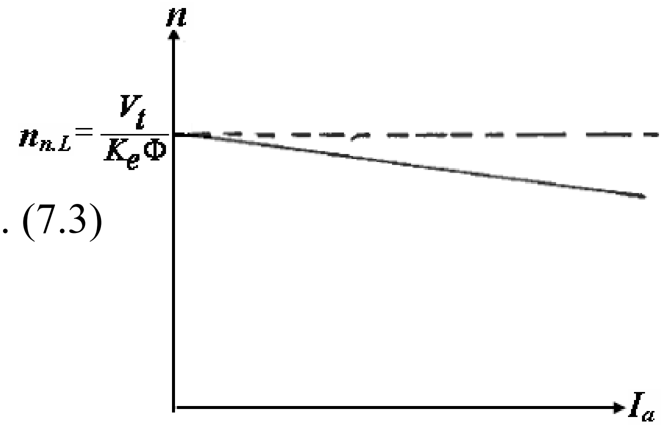

Fig.(7-4)

This eq'n can be written as

$\boldsymbol{T_e = K_t \Phi I_a}$ ………. (7.5)

Where $K_t = \dfrac{K_e}{2\pi}$

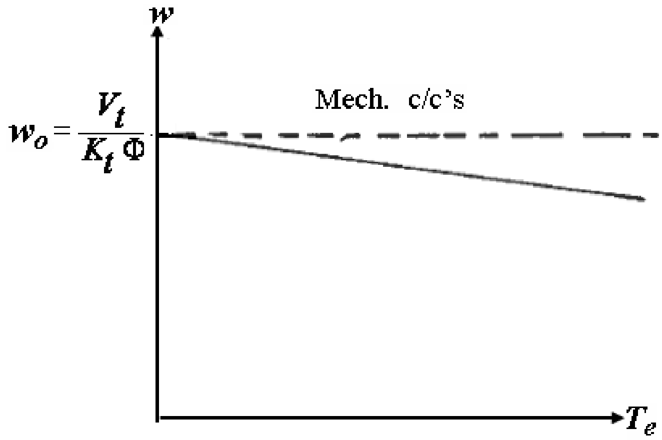

Fig.(7-5)

Sub. (7.5) in (7.2) result in

$$n = \frac{V_t}{K_e \Phi} - \frac{R_a \times 2\pi}{K_e^2 \Phi^2} T_e$$

or $n = \dfrac{V_t}{K_e \Phi} - \dfrac{R_a}{K_e K_t \Phi^2} T_e$ ………. (7.6)

Multiply both sides of (7.6) by 2π result in

$$w = \frac{V_t}{K_t \Phi} - \frac{R_a}{K_t^2 \Phi^2} T_e \qquad \text{………….. (7.7)}$$

This relation drawn in fig.(7.5) showing that the relation with ***Te*** is a linear one.

$T_C = \dfrac{P_C}{w_r}$ loss Torque

But

Tc = Te – To/p from *PDF*

$\therefore$ At no- load $\boldsymbol{T_{o/p} = 0}$

and $\boldsymbol{T_e = T_c}$

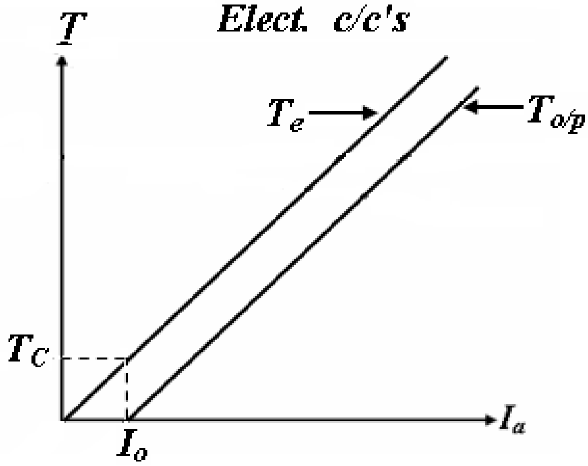

Fig.(7-6) Motor Elect. c/c's

Fig. (7.6) shows eq'n (7.4) which is know as the electrical characteristics (***T versus I***$\boldsymbol{I_a}$), $\boldsymbol{I_o}$, is the no-load current of the motor and $\boldsymbol{T_c}$ is known as the losses torque.

7.3 Shunt- xcited d-c Motor

For this motor, the same series of eq'ns (from 7.1 to 7.7) can be applied to this type of motor and the same c/c's are obtained if we assume the terminal voltage of the power supply feeding the armature is constant during the (starting, run, and transient conditions) operation, which is not the case, hence, field terminal voltage are load dependent, and this will be the cause of many problems as will be shown later on

7.4 Series d-c Motor

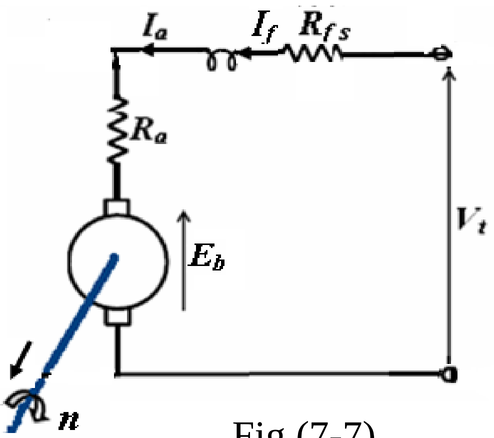

Fig.(7-7)
Equivalent circuit of a d-c series motor

In this type $I_a = I_f$ so $\Phi \; \alpha \; I_a$

Or $\Phi = K' I_a$

$\therefore$ Eq'n (7.5) can be written as

$T_e = K_t K' \, I_a^2$

$T_e = K'' I_a^2 \ldots$ (7.8) (Before saturation)

Where $K'' = K' K_t$

and $T_e = K_t \, \Phi \, I_a$ ……(7.9) (after saturation)

Fig. (7.8) shows (T ***versus*** I_a) which is known as the electrical c/c's of the series motor. It is clear that, the relation is a parabola before the current I_a reaches the saturation value I_{sat} and it is a linear relation for $I_a > I_{sat}$.

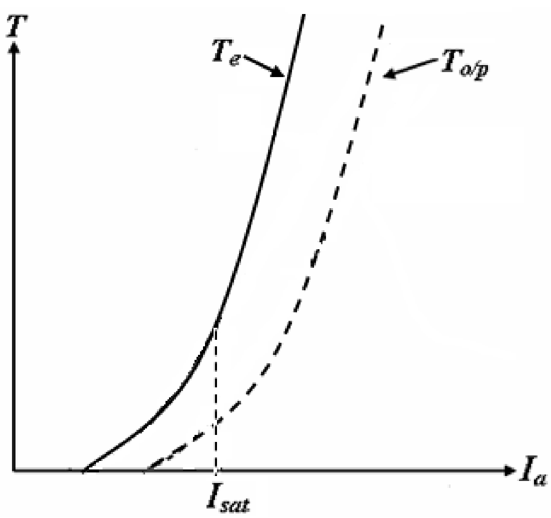

Fig.(7-8)

This behavior means that the generated torque is higher for certain value of I_a as compared with other types of motors.

To study mechanical c/c's of this machine eq'n (7.6) should be considered. It is clear that speed is inversely proportional with, Φ so it is inversely proportional with I_a as well, then at no-load n is very high, which at heavy load n decreased drastically as shown in fig. (7.9). But, as it is well know that as $I_a > I_{sat}$, Φ is constant, then, the drop in speed will be linear as that shown in separate. or shunt motors. Since $T \alpha I_a$, so the speed torque c/c's will have the same shape.

These c/c's leads to special usage of this type of d-c motors.

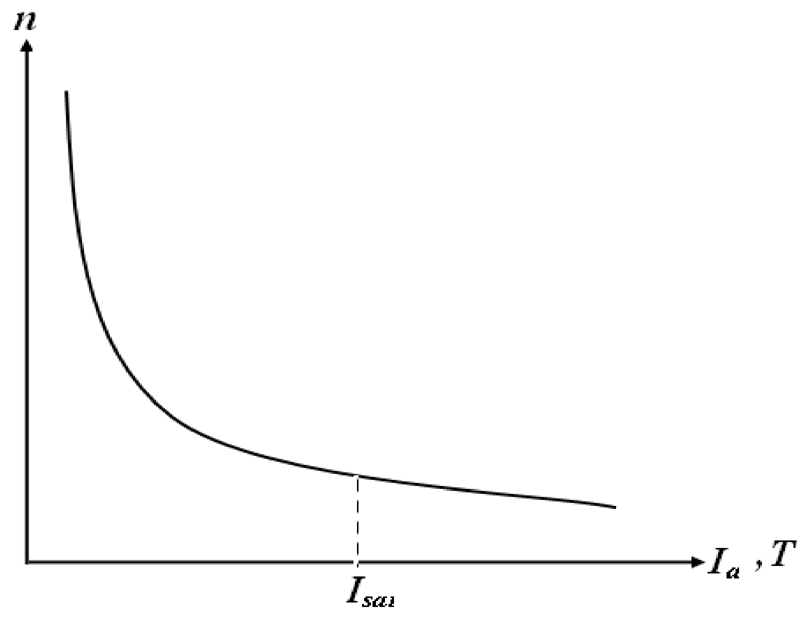

Fig.(7-9)

7.5 <u>mechanical c/c's of loads</u>

As it shown, that there are different (***Torque/speed***) c/c's of motors, there are different (Torque/speed) c/c's of loads. So, the load torque is not constant but it is speed dependent. For example, pushing a car needs high starting torque, but it when moves the torque reduced with speed, while, on contrary, the load of a fan, starts with small torque and the load torque increased with speed, as shown in fig.(7.10).

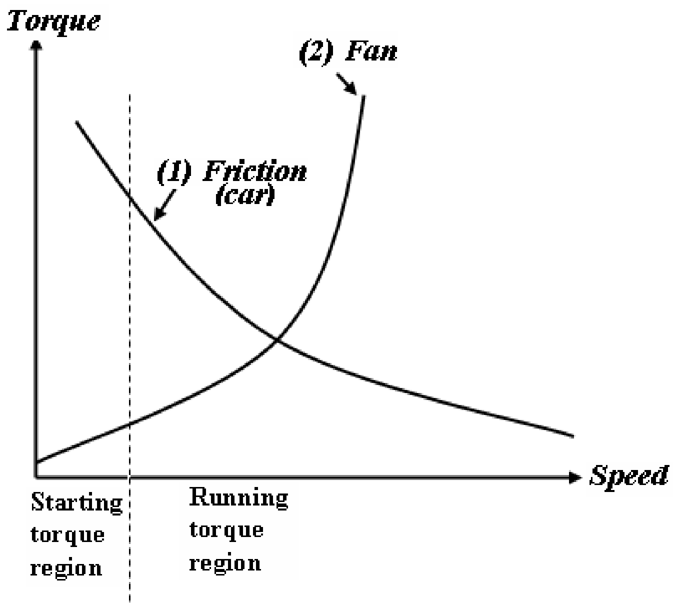

Fig.(7-10)

so load (1) needs a high starting torque motors while load (2) needs a low starting torque motors. Also, some kinds of loads need a constant speed in spite of a different loading condition (in magnitude) like elevators.

Type of load connection with motor, is also an important factor, in that series motor needs not to work at no-load, and load loosing during operation will be very dangerous, because of a high acceleration of speed in that occasion.

Another load needs a variable speed with constant torque operation, while another loads require a soft starting torque, and soft breaking operation like elevators, cranes.

The robot needs to move, stop, and reveres its movement in certain time and with high accuracy. So, the engineer has to take the load c/c's into consideration in order to choose the suitable type of machine and its controller